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The Effect of Visual-Spatial Ability on the Learning of Robot-Assisted Surgical Skills

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BACKGROUND: The aim of this study was to determine the correlation of visual-spatial ability with progression along the learning curve for robotic surgical skills training.

METHODS: A total of 21 novice participants were recruited. All participants completed a training program consisting of 5 training sessions of 30 minutes of virtual reality (VR) simulation and 30 minutes of dry laboratory training. The VR simulation part was the subject of the present study. During VR simulation training, participants performed the basic skill exercises of Camera Targeting 1, Pick and Place, and Peg Board 1 followed by advanced skill exercises of Suture Sponge 1 and Thread the Rings. The visual-spatial ability was assessed using a mental rotation test (MRT). Pearson correlation coefficients were used to assess the relationship between the MRT score and simulator score for the aforementioned 5 tasks. Student *t* test was used to compare the simulator score between high- and low-MRT score groups.

RESULTS: A median MRT score of 26/40 (range: 13-38) was observed. Approximately 19 participants completed the full curriculum but 2 did not complete "Thread the Rings" during the study period. A significant correlation was observed between the MRT score and simulator score only in "Suture Sponge 1" over the first 3 attempts (first: $r = 0.584$, $p = 0.0054$; second: $r = 0.443$, $p = 0.0443$; third: $r = 0.4458$, $p = 0.0428$). After the third attempt, this significant correlation was lost. Comparison of the score for "Suture Sponge 1" between the high-MRT and low-MRT scoring participants divided by a median MRT score of 26 also showed a significant difference in the score until the third trial.

CONCLUSION: Our observations suggest that the spatial cognitive ability influences the initial learning of robotic suturing skills. Further studies are necessary to verify the usefulness of an individual's spatial ability to tailor the surgical training program. (J Surg Ed ■■■■-■■■.)

KEY WORDS: robot-assisted surgery, spatial cognitive ability, mental rotation test, learning curve

COMPETENCIES: Practice-Based Learning and Improvement

INTRODUCTION

Recent advances in minimally invasive surgery have led to several improvements, including reduced pain, less scarring, lower-level blood loss, and earlier recovery to a normal daily life. As a result, laparoscopic and robotic techniques are now widely accepted in general surgery, thoracic surgery, urology, and gynecology. At the same time, the growing complexity of surgical procedures means that surgeons are expected not only to learn the novel techniques but also transfer those skills to the next generation effectively. This must also be achieved in the context of working-hour restrictions, fiscal limitations, and patient safety concerns. Maintaining efficient and effective training is becoming increasingly important, and several previous studies discussed the associations among the visual-spatial ability, acquisition of surgical skills, and prediction of technical aptitude.¹⁻⁶ Wanzel et al.¹ examined several types of visual-spatial ability test, and observed that the mental rotation test (MRT) was the most closely associated with better performance of 2- and 4-flap Z-plasty of surgical residents, and their group also reported a positive correlation between the MRT score and performance on internal fixation of a mandibular fracture.² Another group also reported a positive correlation in reef knot-tying.³ In terms of the relationship between the skills of robotic surgery and visual-spatial ability, there were 2 previous studies, and their observations were

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conflicting.^{7,8} Furthermore, their assessments were performed based on a single session, and not the course of the learning curve. The aim of the present study was to gain further insights in terms of the effect of the visual-spatial ability on robot-assisted surgical skills, focusing on progression along the initial learning curve.

MATERIAL AND METHODS

Participants

This study was approved by the institutional review board, and performed as part of a larger randomized study comparing

cognitive training with standard training. A group of 21 novices in robot-assisted surgery volunteered for and participated in the study. All participants completed a questionnaire on background variables including the age, sex, current status (students or doctor), dominant hand, suturing experience, experience of open, laparoscopic, and robotic surgery, and experience of a laparoscopic or robotic simulator.

Simulation Task

In this study, during the 2-week study period, participants were required to complete a minimum of 5 training sessions consisting of 30 minutes of Xi backpack simulator-training

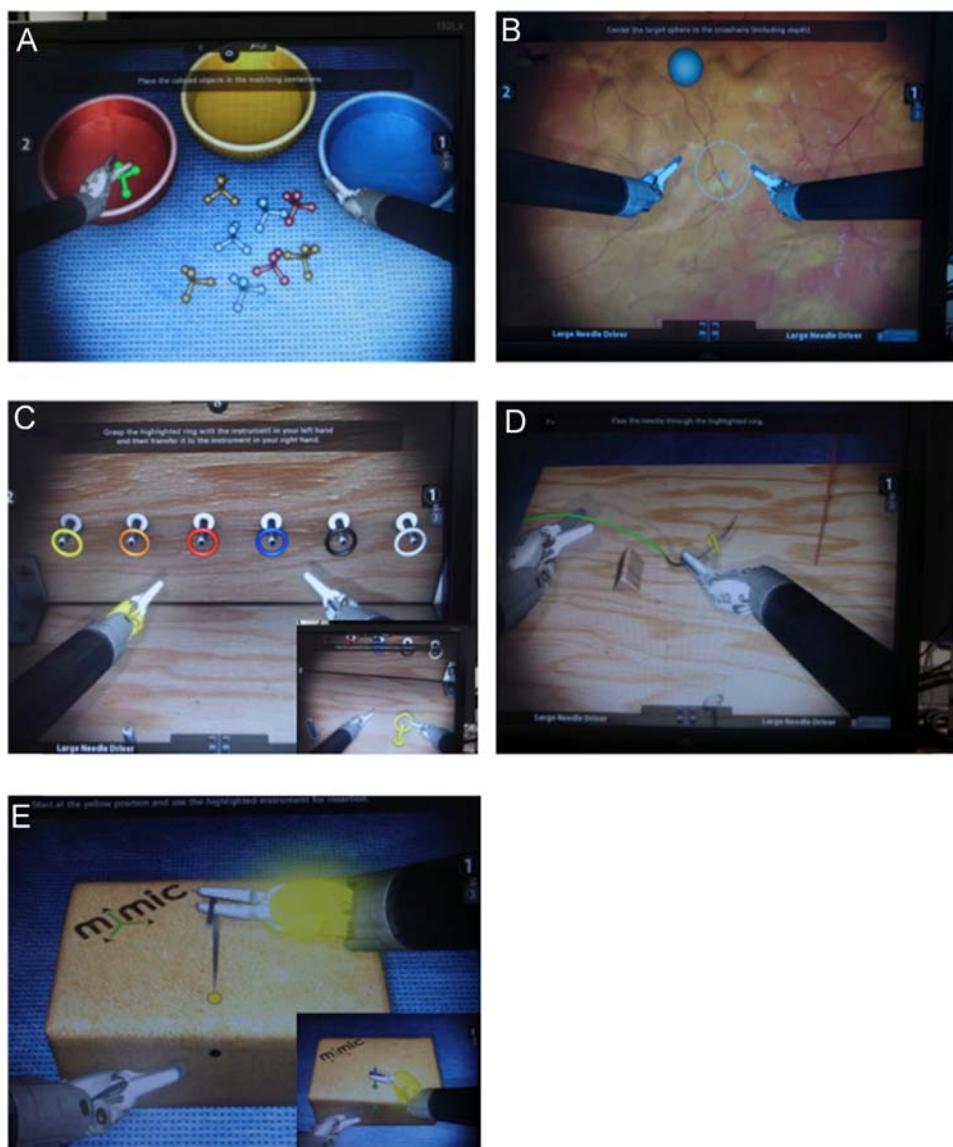


FIGURE 1. Five skill exercises in the present curriculum. (A) Pick and Place: A trainee is required to place colored objects in the matching containers. (B) Camera Targeting 1: A trainee is required to center the target sphere in the crosshairs (including depth). (C) Peg Board 1: A trainee is required to grasp the highlighted ring with the instrument in the left hand, then transfer it to the instrument in the right hand, and place it on the highlighted peg on the floor. (D) Thread the Rings: A trainee is required to pass the needle through the highlighted ring. (E) Suture Sponge 1: A trainee is required to thread the needle through the indicated position using the highlighted instrument for insertion. A trainee is required to finish forehand/backhand suturing tasks with both hands.

TABLE 1. Characteristics of the Participants

	Total, n = 21	MRT Score, > 26, n = 11	MRT Score, < 26, n = 10	p Value
Age, y	Median 23 (range: 20-38)	Median 23 (range: 20-38)	Median 23 (range: 20-30)	0.5688
Sex	M/F = 13/8	M/F = 7/4	M/F = 6/4	0.8639
Doctor/medical student	5/16	2/9	3/7	0.5248
Mental rotation score	Median 26 (range: 13-38)	Median 28 (range: 26-38)	Median 22 (range: 13-25)	0.0001
Number of each study group	Cognitive/control = 11/10	Cognitive/control = 7/4	Cognitive/control = 4/6	0.2766
Suturing experiences				
Instrument tie in simulation, sessions	Median 1 (range: 0-15)	Median 1 (range: 0-15)	Median 1 (range: 1-10)	0.6754
Instrument tie in theater, sessions	Median 0 (range: 0-50)	Median 0 (range: 0-50)	Median 0 (range: 0-10)	0.9066
Hand tie in simulation, sessions	Median 1 (range: 0-15)	Median 1 (range: 0-15)	Median 0.5 (range: 0-10)	0.2814
Hand tie in theater, sessions	Median 0 (range: 0-50)	Median 0 (range: 0-50)	Median 0 (range: 0-10)	0.7774
Open surgical experience				
Observed cases of open surgery	Median 10 (range: 0-200)	Median 10 (range: 0-200)	Median 10 (range: 0-40)	0.4324
Assisted cases of open surgery	Median 1 (range: 0-200)	Median 1 (range: 0-200)	Median 0.5 (range: 0-40)	0.6859
Laparoscopic experience				
Observed cases of laparoscopic surgery	Median 3 (range: 0-25)	Median 3 (range: 0-25)	Median 1.5 (range: 0-15)	0.4938
Assisted cases of laparoscopic surgery	Median 0 (range: 0-20)	Median 0 (range: 0-20)	Median 0 (range: 0-15)	0.8667
Robotic experience				
Observed cases of robotic surgery	Median 0 (range: 0-12)	Median 0 (range: 0-12)	Median 0 (range: 0-2)	0.7773
Assisted cases of robotic surgery	0	0	0	
Simulation experience				
Experience of laparoscopic simulator, h	Median 0 (range: 0-4)	Median 0 (range: 0-4)	Median 0 (range: 0-2)	0.7044
Experience of robotic simulator, h	Median 1 (range: 0-5)	Median 1 (range: 0-5)	Median 1 (range: 0-2)	0.9693

(da Vinci surgical system), and 30 minutes of da Vinci Xi system training (a vertical running suture in a dry box), with an intersession interval of at least 5 hours. The da Vinci surgical system component was the subject of this study, and all participants performed a virtual reality (VR) simulator task under the teaching rules described later. For the da Vinci Xi part, participants in the cognitive study group were asked to mentally rehearse running suture performing during the session interval.

Each training session was performed under the instruction of a trainer (T.A. or N.R.). All participants were required to complete the VR training curriculum described previously.⁹ “Pick and Place,” “Peg Board 1,” and “Camera Targeting 1” provided training on the basics of robotic manipulation. After achieving competency, participants advanced to “Suture Sponge 1” and “Thread the Rings” in the subsequent sessions. Figure 1 summarizes the contents of the 5 training tasks. In the latter sessions, the participants also performed other VR tasks.

Spatial Cognitive Ability

Visual-spatial ability was assessed using a MRT.¹⁰ Using an open data source (Shepard-Metzler resource pack, <http://librebraintraining.org>), we created a Shepard-Metzler task, including 20 questions where each question had 2 correct alternatives to a target shape among 4 choices. One point was awarded for each correct answer, with a full score of 40 points. We also performed a Trail-Making test (TMT), which is commonly used in driving research studies to predict driving difficulty.^{11,12} Briefly, the TMT is a 2-part pencil-paper test. Part A requires the participant to draw lines sequentially connecting 25 encircled numbers randomly distributed on a sheet in numeric order. Part B requires a participant to do a similar task using both numbers and letters (e.g., 1-A-2-B-3-C, etc.). The time to complete each task (seconds) represents the score.

TABLE 2. Summary of Number of Times to Complete the 5 Tasks

	Total, <i>n</i> = 21	MRT Score, > 26, <i>n</i> = 11	MRT Score, < 26, <i>n</i> = 10	<i>p</i> Value
Camera Targeting 1	Median 6 (range: 3-14)	Median 6 (range: 3-14)	Median 4.5 (range: 3-7)	0.1826
Pick and Place	Median 3 (range: 2-10)	Median 4 (range: 2-5)	Median 3 (range: 2-10)	0.8533
Peg Board 1	Median 2 (range: 1-7)	Median 3 (range: 2-7)	Median 2 (range: 1-6)	0.3807
Suture Sponge 1	Median 5 (range: 3-9)	Median 5 (range: 3-9)	Median 5 (range: 3-7)	0.4061
Thread the Rings	Median 4 (range: 0-10)	Median 4 (range: 3-8)	Median 2.5 (range: 0-10)	0.1444

Statistical Analysis

The Pearson correlation coefficients were assessed between each individual's score for the spatial cognitive test and the simulator score calculated by the built-in algorithm for the 5 aforementioned tasks on the completion of the first, second, and third trials. Student *t* test was used to compare the scores between the 2 groups. The Mann-Whitney *U* test was used to compare the background factors of participants, and categorical variables were subjected to the χ^2 test. All statistical analyses were performed using JMP Pro12.01 (SAS). *p* < 0.05 was considered significant.

RESULTS

Table 1 shows a summary of the participants' characteristics. A total of 3 quarters were medical students and most of the participants had very limited surgical experience. Although 16 participants had robotic simulator experience, the median training time was just 1 hour. In the present cohort, the median MRT score was 26 (range: 13-38). There were no significant differences in backgrounds between the high-MRT (> 26) and low-MRT (< 26) participants. About 7 of 11 participants with a high-MRT score and 4 of 10 with a low-MRT score were assigned to the cognitive group (χ^2 test, *p* = 0.2766).

During the study periods, the 19 participants completed at least 5 training sessions (3 performed 6, and 1 performed 7 sessions), and the remaining 2 performed 3 sessions. Table 2 shows the number of times each exercise was completed. Owing to the training curriculum, the number of exercises completed varied among the participants. Overall, the 19 participants completed all the 5 tasks at least once, and the remaining 2 completed all tasks at least once apart from "Thread the Rings."

Table 3 shows the correlation between the overall simulator score and MRT score for the first, second, and third trials of the 5 tasks. A significant correlation was observed for "Suture Sponge 1" in all 3 trials (Table 3 and Fig. 2). For the fourth trial of "Suture Sponge 1," no significant correlation was observed (*r* = 0.3801, *p* = 1084). On analysis of the individual metrics calculated by the simulator for "Suture Sponge 1," a significant correlation between the MRT score and excessive force (first and second), or economy of motion (all 3 trials) in multiple trials was observed (Supplementary Table 1). The

median TMT-A score was 19.7 seconds (range: 12.7-55), and the median TMT-B score was 34 seconds (range: 22.5-80). In the TMT-A score, a significant correlation was observed only in the third Suture Sponge 1 trial (*r* = -0.4354, *p* = 0.0485). No significant correlation was observed for the first, second, and third trials of the 5 tasks in the TMT-B score (data not included).

A comparison of the overall scores for "Suture Sponge 1" according to the MRT score is shown in Figure 3. There was a marginal difference (*p* = 0.0837) for the first, and a significant difference for the second (*p* = 0.0286), and third (*p* = 0.0175) attempts between the high (> 26) and low (< 26) MRT score groups. The difference disappeared after the third trial, although fewer participants did not complete the fourth or subsequent trials (fourth: *n* = 19, *p* = 0.3419; fifth: *n* = 13, *p* = 0.6946; sixth: *n* = 8, *p* = 0.9318). When comparing the overall scores between the 5 participants with the top MRT score and the 6 participants with the bottom MRT score, we observed the same results whereby the high-MRT participants achieved better simulator scores, and the difference decreased after the third trial (Supplementary Fig. 1: for the fourth and fifth trials, the number of participants decreased to 10 and 7, respectively).

TABLE 3. Correlation Between the Overall Score of Each Robotic Training Task for the First, Second, and Third Trials and Mental Rotation Score

	<i>r</i>	<i>p</i> Value
<i>First trial</i>		
Camera Targeting 1	0.0622	0.788
Pick and Place	-0.046	0.843
Peg Board 1	-0.1333	0.5645
Suture Sponge 1	0.5842	0.0054
Thread the Rings	-0.0253	0.9181
<i>Second trial</i>		
Camera Targeting 1	0.4099	0.065
Pick and Place	-0.0625	0.7879
Peg Board 1	0.2178	0.3853
Suture Sponge 1	0.443	0.0443
Thread the Rings	0.1709	0.4843
<i>Third trial</i>		
Camera Targeting 1	0.0935	0.687
Pick and Place	0.1223	0.705
Peg Board 1	0.0406	0.9113
Suture Sponge 1	0.4458	0.0428
Thread the Rings	0.0487	0.8578

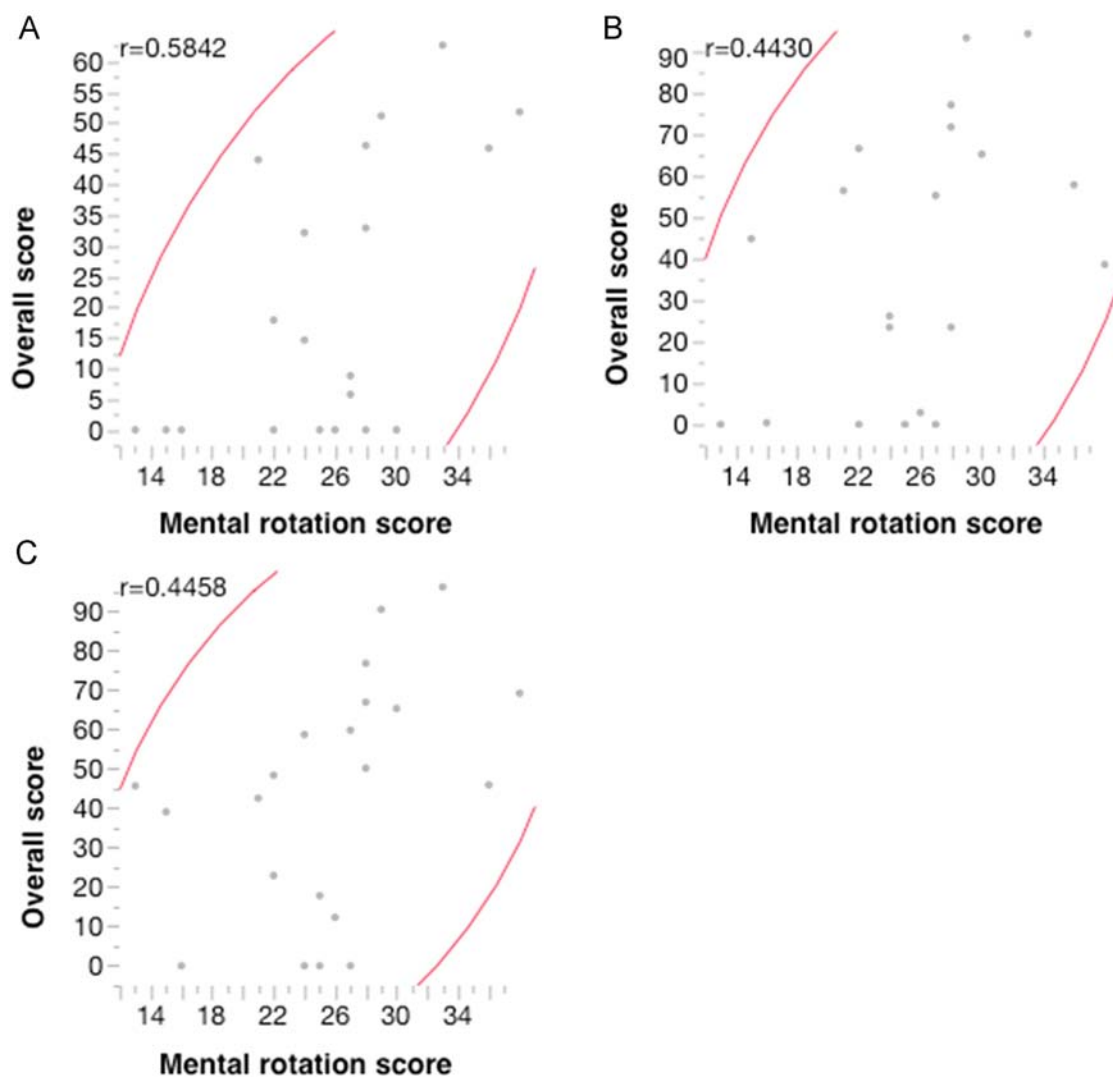


FIGURE 2. Correlation between the overall score of “Suture Sponge 1” and MRT score for the first, seconds, and third trials. A significant correlation was observed in all 3 trials.

DISCUSSION

The ability to recognize position, size, and form precisely and mentally manipulate objects in 3 dimensions could be associated with the process of learning surgical skills. So far, there have been 2 studies on the relationship between visual-spatial ability and the acquisition of robotic surgical skills. Egi et al. reported a negative finding. They divided 20 participants (medical students) into 2 groups according to the MRT score, and compared the laparoscopic skills assessed using their originally developed devices and the robotic skills assessed using the Mimic dV-Trainer. Although they observed a significant difference in laparoscopic skills, no difference was noted in the 4 robotic simulator tasks (“Pick and Place,” “Peg Board,” “Thread the Rings,” and “Suture Sponge”) between the 2 groups.⁷ On the contrary, Teishima et al. subsequently reported that, using the same simulation tasks, a significant correlation was

noted between the overall score of “Peg Board” and “Suture Sponge,” and MRT score in the 20 medical students. However, no significant correlation was noted in any of the 4 tasks in a cohort of 24 urologic surgeons.⁸ They speculated that the effect of daily clinical practice might reduce the influence of the difference in spatial cognitive ability. In both studies, skill assessment was performed once, not over multiple sessions. The MRT score was assessed using the same method where the 3D-shapes were shown in the left and right fields of vision, and the participants were asked to answer whether or not those shapes were the same.

In this study, we observed a significant correlation between robotic suturing skill acquisition and the MRT score during the initial learning phase. For the task of “Suture Sponge 1,” a significant correlation was observed during the 3 initial trials, but it disappeared in the fourth trial. Comparison of the overall score between the high- and

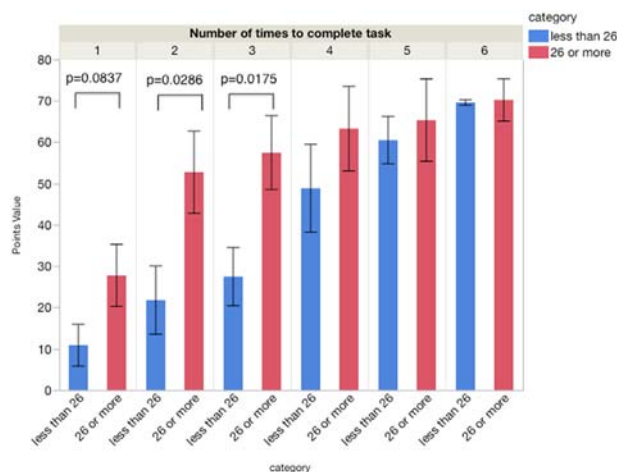


FIGURE 3. Overall score of "Suture Sponge 1" divided by a median MRT score of 26. There was a marginal difference ($p = 0.0837$) at the first, and significant difference at the second ($p = 0.0286$) and third ($p = 0.0175$) between the 2 groups. The difference disappeared after the third trial. Each column represents the mean \pm standard error.

low-MRT score groups also showed a significant difference in the overall score between the 2 groups until the third trial. For the other 4 tasks, we did not observe significant correlations during any of the 3 initial trials, which suggested that the influence of visual-spatial ability on robotic surgical learning would vary among the types of procedure. Among the 5 tasks, all the participants told us that Suture Sponge 1 was the most difficult (data not shown), and we also had the same opinion. In Suture Sponge 1, participants need to determine the correct output orientation of the needle by mentally manipulating it, whereas participants are able to adjust the robotic movements under direct vision in the remaining 4 tasks. That difference might be a reason why the MRT score was significantly correlated with Suture Sponge 1.

TMT was originally developed as part of the Army Individual Test Battery, and previous studies showed its association with driving fitness in older people.^{11,12} Because robotic surgery requires simultaneous hand and foot-pedal manipulation, like driving a car, we evaluated the relationship between its score and robotic skill acquisition. To our knowledge, the association between the TMT score and surgical skill learning was not previously investigated. We did not find any significant correlation for the first, second, and third trials of the 5 tasks in the TMT-B score, although a significant correlation was observed only once between the third Suture Sponge 1 trial and TMT-A score. The observed TMT-A and TMT-B scores were consistent with the age-matched normative data (age: 18-24; TMT-A median = 21.7 seconds; TMT-B: median = 47 seconds).¹³ Based on the present observation, we suggest that the TMT score was not associated with the early learning phase of skill acquisition in robot-assisted surgery, although a larger study is still needed.

Based on the past observation that not all trainees are capable of reaching independent technical competence in

the operating theater after training,^{14,15} the possibility of using surrogate markers of innate ability, such as visual-spatial tests to assess trainees' future performance, has been discussed frequently.^{16,17} Of those visual-spatial tests, the MRT test has frequently demonstrated a positive effect on several open surgical procedures.¹⁻³ The Pictorial Surface Orientation test, designed specifically to test the cognitive ability to recover information on 3-D structures from 2-D monitor displays,¹⁸ has also been repeatedly investigated.^{19,20} Recently, Louridas et al.²⁰ performed a systematic review of background characteristics including cognitive test outcomes, and future technical performance. Among the different visual-spatial tests, MRT and Pictorial Surface Orientation tests have repeatedly shown a positive association with surgical performance, but the evidence was sometimes inconsistent.^{20,21} Furthermore, they pointed out a lack of evidence on the association between innate ability and longitudinal surgical performance, such as the rate of skill acquisition or long-term performance. Based on the previous studies and our observations, we suggest that such cognitive aptitude tests cannot solely be used for resident selection. In the present study, we observed that the lower MRT score group caught up with the higher group after 3 training sessions. Although we believe that there is a potential for these aptitude tests to help tailor initial training activities, further studies are still required to determine whether the objective assessment of innate ability can be helpful for surgical education.

Our study has several limitations. Firstly, the sample size was small. Secondly, as described before, approximately 3 quarters of the participants had previous experience of touching a robotic simulator, although their experiences were very limited and all the participants needed basic instruction in robotic manipulation during the initial session (data not shown). Thirdly, because of our training rule based on the competency of each participant, the number of times to complete each task varied among the participants. Our training rule is a usual method of skills training in the real world, and another study method that fully controls the times and order of each task might provide more robust evidence. Fourthly, as described earlier, this study was performed as part of a larger randomized study comparing cognitive training with standard one. In the cognitive study group, the participants were asked to mentally rehearse running suture during the session interval. This may have had some effect on the learning curves for the VR simulator part. When comparing the overall scores for the 5VR tasks between the cognitive and control groups, there was a marginal difference in Camera Targeting 1 through the 3 initial trials, although we do not have an adequate explanation for the observation (data not shown). In the future, we need to confirm our observation with a larger cohort, ideally in "robotic-null" participants, including additional suturing tasks. Nevertheless, we consider that our observations strongly suggest a positive correlation between

the visual-spatial ability and initial phase of learning robotic suturing skills.

CONCLUSIONS

Our observations suggest that the spatial cognitive ability influences the initial learning of robotic suturing skills. Further studies are necessary to verify the usefulness of an individual special ability to tailor the surgical training program.

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SUPPORTING INFORMATION

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.jsurg.2017.08.017>.